SULPHUR DIOXIDE LEVELS AND ENVIRONMENTAL STUDIES IN THE SUDBURY AREA DURING 1971

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SUMMARY

The Air Quality Branch of the Ministry of the Environment continued to monitor the sulphur dioxide levels in the Sudbury area during the 1971 growing season (May to October). The original monitoring program was set-up in 1953 and consisted of only five instruments. Since 1953 the network has been expanded and modified to give a more complete record of the SO2 levels around Sudbury. During 1971 a total of 11 Thomas autometers were operated at locations where vegetation has been damaged by SO2 during previous seasons.

A total of 78,396 half-hour readings were measured during 1971. Of this total 68,073 (86.8%) were zero readings and 10,323 (13.2%) were SO2 readings. The SO2 readings ranged from 0.01 ppm to 1.97 ppm. Of the total SO2 readings 11.2% were above 0.25 ppm, 2.98% were above 0.50 ppm and 0.42% above 1.00 ppm.

During the 1971 season 61 fumigations were recorded which exceeded the levels generally considered to be damaging to vegetation. The Grassy Lake, Sturgeon Falls, and St. Charles stations were the only stations where potentially injurious fumigations were not recorded at some time during the season. Twenty four potentially injurious fumigations were recorded at Skead, 18 at Garson, eight at Rayside, five at Kukagami Lake, three at Lake Penage and one each at Morgan, Burwash, and Callum

Vegetation was injured by SO2 to some extent in the Sudbury area during May, June, July, August, and September. The most severe injury occurred relatively late in the growing season and was caused by three separate fumigations.

A number of complaints of vegetation injury were received and investigated by the Phytotoxicology Section of the Air Quality Branch during 1971. In most cases the reported injury was caused by SO2 and after the results of the investigations were available a report was sent to the complainant and the offending company.

In 1970 samples of vegetation and soil were collected in June, July, August, and September at 15 locations in the Sudbury area and two locations outside of the fume damage region. These samples were chemically analyzed for several elements. The results of this analysis show that the vegetation and the soil in the Sudbury area contain elevated levels of several elements when compared to the check locations. The highest levels of contamination occur to the northeast of Sudbury in the Skead and Kukagami Lake areas. In general, the levels of the various elements decrease with increasing distance from Sudbury.

The levels of total sulphur and sulphate-sulphur in the vegetation are highly correlated to the amount of SO2 in the air near the sampling stations as measured on lead peroxide candles.

Samples of vegetation and soil were collected in 1971 and are presently being analyzed in a manner similar to that of the 1970 samples. Sampling will continue in 1972 and a close surveillance of the vegetation will be maintained in order to determine the effect of the Sudbury area smelters on the environment.

I. Introduction

In 1953 the Ontario Government set up a network of instruments to measure the ground level concentrations of sulphur dioxide in the Sudbury area. Initially the network was made up of five instruments situated at locations where vegetation damage has occurred in previous seasons. Since 1953 additional sampling stations have been established to give a more detailed record of SO2 levels in the fume damage area. During 1971 a total of 11 autometers were operated during the growing season. The most recent addition to the network is the station at Sturgeon Falls, 48 miles east of Sudbury. Fig. 1 and table 1 show the locations of the 11 stations in relation to the area smelters and the city of Sudbury. This report summarizes the data collected during the 1971 growing season.

A detailed surveillance program was carried out in the Sudbury area during 1971 to determine the incidence and degree of vegetation damage caused by the fumigations recorded at the area sampling stations. A month by month record of all vegetation damage is included in this report.

In 1970 a sampling program was set up in the Sudbury area by the Phytotoxicology Section, Air Quality Branch to determine the levels of the various elements in the vegetation and soil in the area. Fifteen stations were established in the area where vegetation had been damaged to some extent by SO2 during previous seasons. Two additional check stations were established at Mattawa and Blind River. The results of the chemical analysis of the samples collected in 1970 is included in this report. The sampling was repeated in 1971, however the chemical analysis was not completed at the time this report was prepared.

II. Sulphur dioxide measurements (a) Daily measurements

During 1971 the Thomas autometers were operated from about the middle of May until the end of October. During this time a total of 78,396 half-hour readings were taken. Of this total 68,073 (86.8%) were zero readings and 10,323 (13.2%) were SO2 readings. The readings ranged from 0.01 ppm to 1.97 ppm. Of the total number of SO2 readings 11.2% were above 0.25 ppm, 2.98% above 0.50 ppm and 0.42% above 1.00 ppm.

In the following table the number of days each recorder was operative is listed as well as the number of days SO2 was recorded and the maximum half-hour readings at each station.

Station	No. of operative days	No. of days in which SO_2 was recorded	Max. ½-hr. concentration (ppm)	Date
Garson	180	120	1.46	June 6
Skead	178	133	1.97	September 2
Kukagami	130	67	1.40	September 25
Grassy	123	60	0.32	July 6
Penage	165	46	0.91	August 13
Morgan	171	103	0.71	September 27
Burwash	168	56	0.68	September 13
Rayside	175	60	1.37	October 20
St. Charles	164	46	0.25	July 18
Callum	152	88	1.22	August 22
Sturgeon Falls.	184	49	0.21	May 10

(b) Monthly measurements

During 1971 SO2 levels greater than 0.25 ppm were recorded sometime during the season at all the stations except Sturgeon Falls and St. Charles (see table 2). Concentrations greater than 0.25 ppm were recorded each month of the season at the Garson, Skead, Kukagami Lake, Callum, and Rayside stations. The 0.25 ppm level was exceeded at the Morgan and Penage stations during every month except July. At Burwash levels in excess of 0.25 ppm were recorded every month except June.

Sulphur dioxide concentrations greater than 0.50 ppm were recorded every month of the season at the Skead and Callum stations, and each month except October at Garson. Levels of SO2 greater than 0.50 ppm were recorded at Rayside during May, June, September, and October. Fumigations with concentrations greater than 0.50 ppm occurred at Burwash in August and September, at Morgan in June, September, and October, and at Kukagami Lake during July, August, and September. Concentrations greater than 0.50 ppm did not occur during the season at the Grassy Lake, St. Charles or Sturgeon Falls stations.

Concentrations in excess of 1.00 ppm were recorded during the season at Garson, Skead, Kukagami Lake, Callum and Rayside. This level was exceeded every month except October at Garson and every month except August at Skead. Sulphur dioxide concentrations greater than 1.00 ppm were recorded at Rayside during June, September, and October, at Kukagami Lake during July, August, and September, and at Callum in September.

(c) Yearly measurements

In table 3 of this report the SO_2 data collected during the 1971 season are compared to the data collected during previous seasons. Sulphur dioxide was recorded more frequently at the Skead and Morgan stations in 1971 than in any previous year of operation. The high frequency of southwest winds during 1971 (see table 4) would account in part for the abnormally high incidence of SO_2 fumigations at the Skead station. Southeast winds would be required to carry the sulphur dioxide from any of the three Sudbury area smelters to the Morgan station. Even though southeast winds were not more common in 1971 than in previous years, SO_2 was recorded at the station more frequently during 1971 than in any other year of operation.

The percentage frequency of SO_2 readings above 0.25 ppm during 1971 ranged from 0.00% at Grassy Lake, St. Charles and Sturgeon Falls to 5.80% at Skead. Since 1953 fumigations with concentrations in excess of 0.25 ppm have been recorded more frequently at the Skead station than any other station.

A maximum half-hour concentration of 3.64 ppm was recorded at the Skead station during 1956. This is the highest half-hour SO_2 concentration ever recorded in the Sudbury area. The maximum half-hour concentration during 1971 was 1.97 ppm and this too occurred at the Skead station.

III. Potentially injurious fumigations

Whether or not vegetation is injured by a particular fumigation of sulphur dioxide is influenced by a number of factors. The concentration of the SO_2 and the duration of the fumigation are two important factors in this respect. A high level of SO_2 for a short period of time can be equally as damaging to vegetation as a lower level of SO_2 for a more prolonged period fo time. In an effort to combine these two factors, an intensity factor has been calculated for each fumigation, based on the average daytime SO_2 concentrations over periods of 1,2,4, and 8-hour intervals. Observations made over the years have indicated that most vegetation injury by SO_2 occurs when the following SO_2 levels are reached or exceeded:

0.95 ppm for 1 hour
or 0.55 ppm for 2 hours
or 0.35 ppm for 4 hours
or 0.25 ppm for 8 hours

For convenience, a factor of 100 has been assigned to any one of the above combinations of concentrations and duration. In some cases.

injury to vegetation has resulted from fumigations with intensities of less than 100 and frequently fumigations of SO2 with intensities of over 100 have been recorded and no injury to vegetation has resulted. This is due partly to the variation in sensitivity to SO2 between plant species. For example,white pine and trembling aspen are considered to be quite sensitive to SO2 while white oak and white spruce are considered to be quite resistant. In addition to there being variation in sensitivity to SO2 from plant species to plant species there is also variation in sensitivity to SO2 within the species. The time during the season when the SO2 fumigations occur also influences the extent of vegetation injury. In general,during June, July, and August when the photosynthetic rate in vegetation is relatively high,vegetation injury in sensitive plant species results from fumigations with intensities of around 100. During the months of September and October when the photosynthetic rate in vegetation is considerably lower than in earlier months fumigations with intensities in excess of 100 often occur with no resultant injury to even the sensitive plant species.

In the following table the data concerning the potentially injurious fumigations which occurred during the 1971 season are summarized:

Station	No. of fumig. with intensities over 100	No. of fumig. with intensites over 75	Max. Int.
Garson	18	30	240
Skead	24	36	252
Kukagami L.	5	12	220
Grassy L.	0	0	57
Penage	3	6	120
Morgan	1	4	126
Burwash	1	1	106
Rayside	8	11	188
St. Charles	0	0	26
Callum	1	5	136
Sturgeon Falls	0	0	25
Total	61	105	

During 1971 potentially injurious fumigations were recorded during the season at all stations except Sturgeon Falls, Grassy Lake and St. Charles. A total of 24 such fumigations were recorded at the Skead station. A total of 61 potentially injurious fumigations were recorded at all 11 stations. One hundred and five fumigations

with intensities of greater than 75 were recorded during the season. The maximum intensity for the 1971 season was recorded at the Skead station on September 2, 1971. The maximum intensity ever recorded in the Sudbury area was 473 and this occurred at the Skead station in 1968. (table 5)

The approximate areas subjected to 20 or more, 10 or more and 1 or more potentially injurious fumigations is shown in figure 2 .

During the past few years the areas subjected to potentially injurious fumigations has varied greatly. In the table below the figures for the 1971 season are compared to those of the 1970 and 1969 seasons.

Year	Area in square miles subjected to at least		
	1 potentially injurious fumigation	10 potentially injurious fumigations	20 potentially injurious fumigations
1969*	1335	75	0
1970	1710	453	44
1971	1950	380	75

IV. Vegetation injury during 1971

(a) Injury by SO2

A detailed surveillance program was carried out by the Phytotoxicology Section of the Air Quality Branch during 1971 to determine the incidence and extent of vegetation injury by SO2 in the Sudbury area. While injury was not as common or widespread as in some of the previous seasons injury did occur during each month of the growing season. In the latter two months intense SO2 fumigations occurred which caused injury over large areas. In previous years vegetation has been damaged at isolated locations as far as 60 miles from Sudbury. In most cases injury at these distances was trace in nature and confined to species which are sensitive to SO2. During 1971 no injury occurred beyond a distance of about 30 miles from Sudbury.

A number of complaints of vegetation injury were received and investigated by the Phytotoxicology Section during 1971. In each case a report on the findings of the investigation was sent to the complainant and the offending company and settlements have

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* 1969 - strike year

been negotiated between the two parties. About one third of the complaints were made by residents of the city of Sudbury and the remainder by residents in the area surrounding Sudbury. In most cases the investigations showed that vegetation had been injured to some extent by sulphur dioxide.

Vegetation injury by SO_2 during May of 1971 was not common. The only injury observed occurred late in the month on vegetables near Falconbridge. The 1971 growing season was about two weeks later than normal in starting. Therefore, even though potentially injurious fumigations did occur on several occasions in May, no vegetation injury resulted from these fumigations.

Vegetation injury by SO_2 during June of 1971 was not as common as in most previous seasons. Weather data collected at the Sudbury Airport indicated that June 1971 was the warmest and driest June since 1955. Weather conditions such as these are not conducive to vegetation injury by SO_2.

Trace SO_2 injury occurred on a few trembling aspen trees about 20 miles northeast of Sudbury early in June. Several trembling aspen trees were injured about 10 miles north of the Callum recorder around the first of the month.

On June 18, 1971 a fumigation occurred in the New Sudbury area which caused trace (1-5% of the leaf area damaged) to severe injury (over 35% of leaf area damaged) on rhubarb, radish, carrot, sweet william, white birch, trembling aspen, and Chinese elm. Damage to some extent was observed over approximately a three square-mile area as a result of this fumigation.

Trace to severe injury occurred on white birch and trembling aspen in mid June along highway 69 North for a distance of about 7 miles north of Sudbury.

Fumigations around the middle of June caused trace to light (6-15% of leaf area damaged) injury in the area to the southwest of Sudbury. Species such as white birch, trembling aspen and basswood were injured to some extent at distances of up to 12 miles to the southwest of Sudbury.

Agricultural crops such as oats, barley, and red clover were injured in an isolated area about 10 miles northwest of Sudbury in late June. Most of the injury on these crops was trace in nature.

Trace injury occurred on sensitive species of vegetation in the Sudbury area on several occasions during July.

While vegetation injury was not widespread during August two separate fumigations occurred which caused severe injury on a number of plant species in two separate locations.

A fumigation occurred in the New Sudbury area on August 9, 1971 which caused severe injury on flowers, vegetables, and trees. Lombardy poplar was the most severely damaged plant species with up to 50% of the leaf area damaged on some trees. The average half-hour concentrations of SO_2 recorded at the nearest autometer located at Garson on the morning of August 9 were in the area of 1.00 ppm with a maximum half-hour concentration of 1.21 ppm occurring between 10:00 and 10:30 a.m. The intensity of this fumigation was 237, over twice the level required for the fumigation to be potentially injurious to vegetation. Several complaints of vegetation injury were received and investigated by the Phytotoxicology Section following this fumigation.

Fumigations which occurred in Waters Twp. (southwest of Sudbury) in mid August caused severe damage on white birch, white pine, trembling aspen, hawthorn and bracken fern. Flowers and vegetables were injured in varying amounts by these fumigations. Several complaints of vegetation injury were received and investigated by the Phytotoxicology Section following these fumigations.

In the area around West Bay of Lake Wanapetei trace injury occurred on white birch, white pine and trembling aspen about the middle of August.

In previous seasons, vegetation injury due to SO_2 has not been common in the Sudbury area during September. However, in the early part of September 1971, the two most severe fumigations for the season occurred which caused extensive injury over large areas.

The first of these fumigations caused severe injury to white birch, trembling aspen, jack pine, and red pine in the area from the Canadian Armed Forces Base on highway 545 through to Capreol on highway 69. From Capreol to Milnet along highway 545 the injury became less severe as the distance from Sudbury increased. It is estimated that the area affected was approximately two miles wide and ten miles long, or about 20 square miles.

The second intense fumigation occurred in the Long Lake area, approximately 5 miles southwest of Sudbury. In this incident, white birch and trembling aspen stands were severely injured causing the foliage to turn brown over nearly all of the leaf area. As well, the current and one year-old needles on jack pine and red pine were damaged in moderate amounts. The area which was affected to the greatest degree was between Long Lake and Tilton Lake in Broder and Tilton townships. Less extensive damage occurred

from Tilton Lake to Wavy Lake, also in Tilton township. The total area affected was estimated to be about 25 square miles.

White Pine injury in the Penage area since 1965

Eastern white pine in the Lake Penage area has been severely damaged by SO_2 in past years. In 1966 a 3-acre study plot was set-up at the east end of the lake. One hundred living trees of varying ages and sizes were selected and tagged. The trees have been examined twice a year since 1966. At the time of each examination the presence of SO_2, insect, or pathological damage has been recorded. The crown condition was also noted according to a scale of 1 to 10, where 1 would be assigned to a tree with a normal crown and 10 to a tree which is dead. Once a year the diameter and height of the selected trees were measured.

Most of the tagged trees were severely damaged in 1965, 1966, 1967, and 1968. There was no SO_2 injury on the trees in 1969 and 1970 and only a trace of injury on a few of the small trees during 1971. No insect or pathological injury of consequence has been observed on any of the tagged trees during the six years they have been studied.

The following table illustrates the changes that have been observed over the period from 1966 to 1971:

Year	No. of dead trees	No. of living trees	No. of trees which died during the year	% of the trees which died each year
1966	0	100	0	0.0
1967	8	92	8	8.0
1968	21	79	13	16.4
1969	34	66	13	19.7
1970	38	62	4	6.4
1971	41	59	3	5.1

Even though the selected trees have not been exposed to any severe SO_2 fumigations during the past three years the mortality rate remains abnormally high for this area. This is probably due to the fact that the trees were unable to recover from the severe fumigations which they were exposed to in 1965, 1966, 1967, and 1968.

By the end of 1971, 21 of the living trees appeared to have a normal crown condition and to be growing at a normal rate. Thirty one of the living trees had suffered various degrees of damage to

their crowns. If these trees are not exposed to damaging SO_2 fumigations or plant disease they will likely survive. Eight of the living trees had a crown rating of 7, 8, or 9 by the end of 1971 and it is not likely that these individuals will survive.

It should be pointed out that the high mortality rate of 41% was measured at only one location and cannot be applied to the whole Lake Penage area. As well, this rate cannot be applied to other tree species since resistant trees such as red oak growing beside the tagged white pine trees were not injured by any of the fumigations which injured the white pine.

During the 1972 season, the Penage study will be continued in addition to the detailed surveillance being carried out in the Sudbury area to determine the incidence and extent of vegetation injury by sulphur dioxide.

IV (b) Vegetation Injury by other agents

During the 1971 surveillance to discern whether vegetation damage due to air contaminants was taking place, other pathological abnormalities were recorded to differentiate such damage from air pollution problems.

In the region of intense SO_2 concentrations (10 or more potentially injurious fumigations per year) the main species present in natural forest stands are white birch, trembling aspen, red pine and jack pine. Each year as noted above these species are injured by sulphur dioxide and are not infected to any great degree by fungal pathogens. Therefore, except where noted, most of the pathological problems described below were encountered outside of the intensive fume damage area.

Physiogenic Diseases

Winter Drying

Winter drying is sometimes prevalent on coniferous trees in this area during midwinter or early spring. It usually occurs after a period of cold weather when there is a sudden increase in temperature accompanied by drying winds which cause an excessive loss of water from the foliage which cannot be replaced because the roots, trunk, and soil, are still in a frozen state. The disease manifests itself by browning of the foliage on the south and southwest sides of the trees. If the damage is not too severe the trees appear more of less normal after the new green shoots are formed. The problem of winter drying is most evident in the pine plantations south of Sudbury on highway 69 near Burwash and west of Sudbury on highway 17 between Espanola and Massey.

Salt Damage

Salt is applied in extensive quantities to the highways in the Sudbury area during the winter months to combat hazardous driving conditions in northern Ontario. Vehicular traffic whips up a salt-laden spray which is carried by winds to roadside vegetation. The needles of coniferous trees turn brown under the influence of excessive salt.

Fungal Diseases

In the Sudbury District there are several diseases incited by fungal pathogens which cause the host trees to exhibit symptoms which might be mistaken for air pollution damage.

White pine infected with the fungus Cronartium ribicola exhibit the syndrome known as White Pine Blister Rust. There is usually a large amount of pine gum exuding from the cankers which form on the trunk and branches. Such trees have browning needles on the portions of the stem or branches distal to the girdling canker. The trees die down from the top giving them a typical "spike top" appearance. This disease is most prevalent to the south and southeast of Sudbury, especially in the St. Charles area.

Dutch Elm Disease is also very prevalent, especially along highway 17 to the east and west of Sudbury. The water transport system of the host (American elm) is infected by a fungus Ceratocystis ulmi causing wilting. The leaves in the upper crown become yellow to brown in July and August. Eventually the branches become dry and the entire tree succumbs.

The leaves of red maple in this area are affected by a fungus called Gloeosporium apocryptum which causes a disease known as Red Maple Anthracnose. Large necrotic areas form on the leaves. Unlike SO_2 damage which is usually intercostal, these necrotic areas cross over the veinal tissue. This disease is widespread to the west amd south of Sudbury.

On two occasions in the Falconbridge area, peach leaf willow has been found to be infected with a combination of two fungal pathogens which cause a disease known as Scab and Black Canker of Willow. The first fungus (Fusicladium saliciperdum) attacks the leaves causing them to turn black before they dry and shrivel. The second fungus (Physalospora miyabeana) causes cankers on the branches and trunk of the willow trees. Successive infections soon cause death to the damaged trees.

Leaves of many trembling aspen in the Sudbury area are affected by the fungus Sclerotinia whetzelii which causes the formation of small, black circular to ellipsoid "ink" spots.

The aspens and poplars in the Sudbury area have been damaged by two canker-causing fungi: Hypoxylon pruinatum and Cytospora chrysosperma in both urban and forest environments. These fungi cause the formation of cankers on the stems of infected aspens and poplars. The cankers girdle the main stem to cause the death of the tree; or they may weaken the tree making it more susceptible to other damaging agents.

Insects

During complaint and surveillance investigations for air pollution injury to vegetation a number of insect problems were encountered in the Sudbury area. Birch leaf miner (Fenusa pusilla) caused widespread damage to white birch to the east of Sudbury along highway 17. This insect is found in the mesophyll tissue of the leaf and it devours this tissue causing large necrotic areas which can be similar to SO_2 injury. To the north of Sudbury, balsam fir and white spruce were badly damaged by Spruce Budworm (Choristoneura fumiferana). The damage is a result of the feeding on the current needles by the larval stage of this moth. Also to the north of Sudbury, the Large Aspen Tortrix (Choristoneura conflictana) fed extensively on the young leaves of tembling aspen in the early summer. In July and August secondary foliage flushes usually returned these affected trees to their former healthy condition.

In response to a request to investigate suspected SO_2 injury to jack pine forests in the French River region to the south of Sudbury, it was found that the Jack Pine Budworm (Choristoneura pinus pinus) was responsible for severe damage to the jack pine populations over an area of approximatly 80 square miles. The method of attack is similar to that of the spruce budworm and in some areas the mortality rate is extremely high.

Vegetation abnormalities will continue to be recorded as part of the 1972 air pollution surveillance program in the Sudbury area since a full understanding of the forest problems is necessary in this fume damage area in order to properly evaluate the effects of air pollutants on the forest ecosystems.

V. Results of 1970 Vegetation and Soil Sampling Program

During the 1970 growing season the Phytotoxicology Section of the Air Quality Branch established 15 permanent vegetation and soil sampling plots in the territory affected by the Sudbury area smelters and two control plots in areas remote from Sudbury. These plots are located as follows:

Plot	Distance and Direction from Sudbury	
Blind River	100 miles W	control plots
Mattawa	110 miles E	
Sudbury	Laurentian University	
Garson	3 miles NE	
Skead	16 miles NE	
Kukagami Lake	26 miles NE	
Grassy Lake	40 miles NE	
Timagami	50 miles NE	
Rayside	10 miles NW	
Morgan	15 miles NW	
Milnet	23 miles N	
Callum	18 miles E	
St. Charles	30 miles SE	
Sturgeon Falls	48 miles E	
Burwash	17 miles S	
Nairn Centre	30 miles SW	(for plot locations
Penage	23 miles SW	see Fig. 3)

At each station, the current and one-year old needles of jack pine, and the leaves from trembling aspen, white birch, bracken fern, and forage, as well as soil (0-4") were collected in June, July, August, and September. In 1970, 298 vegetation and 34 soil samples were collected and these samples were analyzed for total sulphur, sulphate-sulphur, arsenic, cobalt, copper, fluoride, iron, nickel, selenium, and zinc. This sampling program was continued in June, July, and September during 1971 when 258 vegetation and 34 soil samples were collected. The 1971 samples were similarly analyzed except that fluoride was deleted from the list.

At the time of writing this report the full analysis of the 1971 samples was not yet complete. However the 1970 data have been compiled and subjected to statistical analysis. Table 6 shows the average concentrations of the various elements in the different species (four monthly collections) and the soil (two monthly collections). Those values for the fifteen surveillance plots which differ markedly from the control plots have been underlined to set them apart from the other figures.

The table of analysis of variance (Table 7) shows that the levels of total sulphur, sulphate-sulphur, copper, iron, nickel, and selenium are significantly different from species to species at the 1% level, while the levels of arsenic, cobalt, and fluoride are similar for most species. This indicated that the levels of a given element in a single species are not necessarily comparable to the levels of that element in other species. For all elements except cobalt and fluoride the levels of the various chemicals are significantly different from station to station at the 1% level.

From Table 6 the following trends are apparent:

1. The levels of cobalt and fluoride were all low and uniform for all species and stations.

2. The levels of selenium and zinc varied randomly, well-within the normal limits for all species and stations.

3. The levels of total sulphur, sulphate-sulphur, copper, iron, and nickel are elevated for most species and soil especially in the plots located to the northeast of Sudbury (i.e. Sudbury, Garson, Skead, and Kukagami Lake).

4. Generally, the levels of contamination decrease with increasing distance from the source.

The predominance of southwest winds in the Sudbury area during the growing season carries the plumes into the northeast sector for the majority of the time. This is reflected in the higher levels of contamination in most species and soil for most elements to the northeast of Sudbury. Skead and Kukagami Lake are the two locations where the greatest contamination occurs. These stations lie to the northeast of Copper Cliff and as well they are influenced by the proximity of the Falconbride complex. At Grassy Lake (40 miles NE) and Timagami (50 miles NE) the levels of contamination decrease, with more normal concentrations appearing in vegetation and soil. In the other sectors, problems are more scattered, although total sulphur and iron appear to be elevated at many locations.

The increased levels of the various chemical elements in the soil and vegetation is another parameter illustrating the effect the Sudbury area smelters are having on the environment. Such elevated values can be correlated to atmospheric sulphur levels. An example of such a relationship is that the sulphation rate measured on lead peroxide candles near several of the vegetation plots is highly correlated to the total sulphur and sulphate-sulphur levels in vegetation collected at these plots (Table 8 and Figs. 4 & 5). For these calculations the total sulphur and sulphate-sulphur values for all of the vegetation samples for each station were combined and the mean and the standard error were determined in each case. When plotted against the sulphation rates, the regression equations and the correlation coefficients were determined. For total sulphur the correlation coefficient (r) is 0.73 and for sulphate-sulphur it is 0.80. Both of these values are statistically significant at the 5% level.

This program of sampling and analysis will continue in the 1972 season to determine any fluctuation in the levels of these various elements in vegetation and soil as a result of changes in metal production and the implementation of abatement measures.

VI. Acknowledgments

The writers wish to express their gratitude to Dr. S.N. Linzon, Chief of the Phytotoxicology Section, Air Quality Branch for his advice and supervision; to Mr. Ken Waldie for maintaining the autometers; to Mr. D. Ogner for compiling the SO_2 data; to Mr. B. Chai for statistical analysis of the data; to Mr. A. Rayner and his staff in Laboratory Services for analysis of samples and to Mrs. J. Springer for secretarial assistance. The contribution and cooperation of these people have made possible the presentation of this report.

VII Appendix

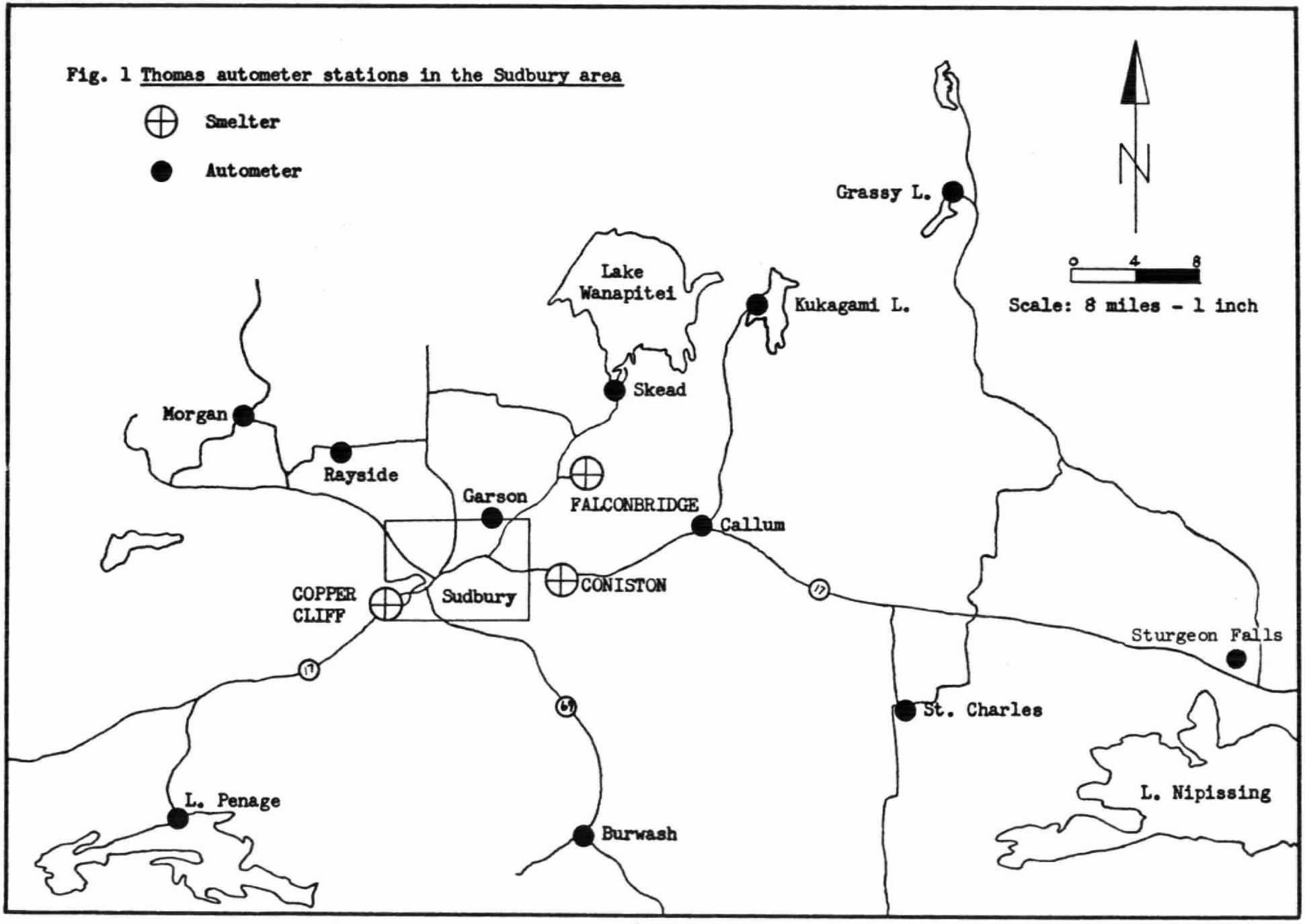
Fig. 1 Thomas autometer stations in the Sudbury area
Smelter
Autometer
N
0 4 8
Scale: 8 miles - 1 inch
Grassy L.
Lake Wanapitei
Kukagami L.
Skead
Morgan
Rayside
Garson
FALCONBRIDGE
Callum
CONISTON
COPPER CLIFF
Sudbury
17
Sturgeon Falls
St. Charles
L. Nipissing
L. Penage
Burwash
69

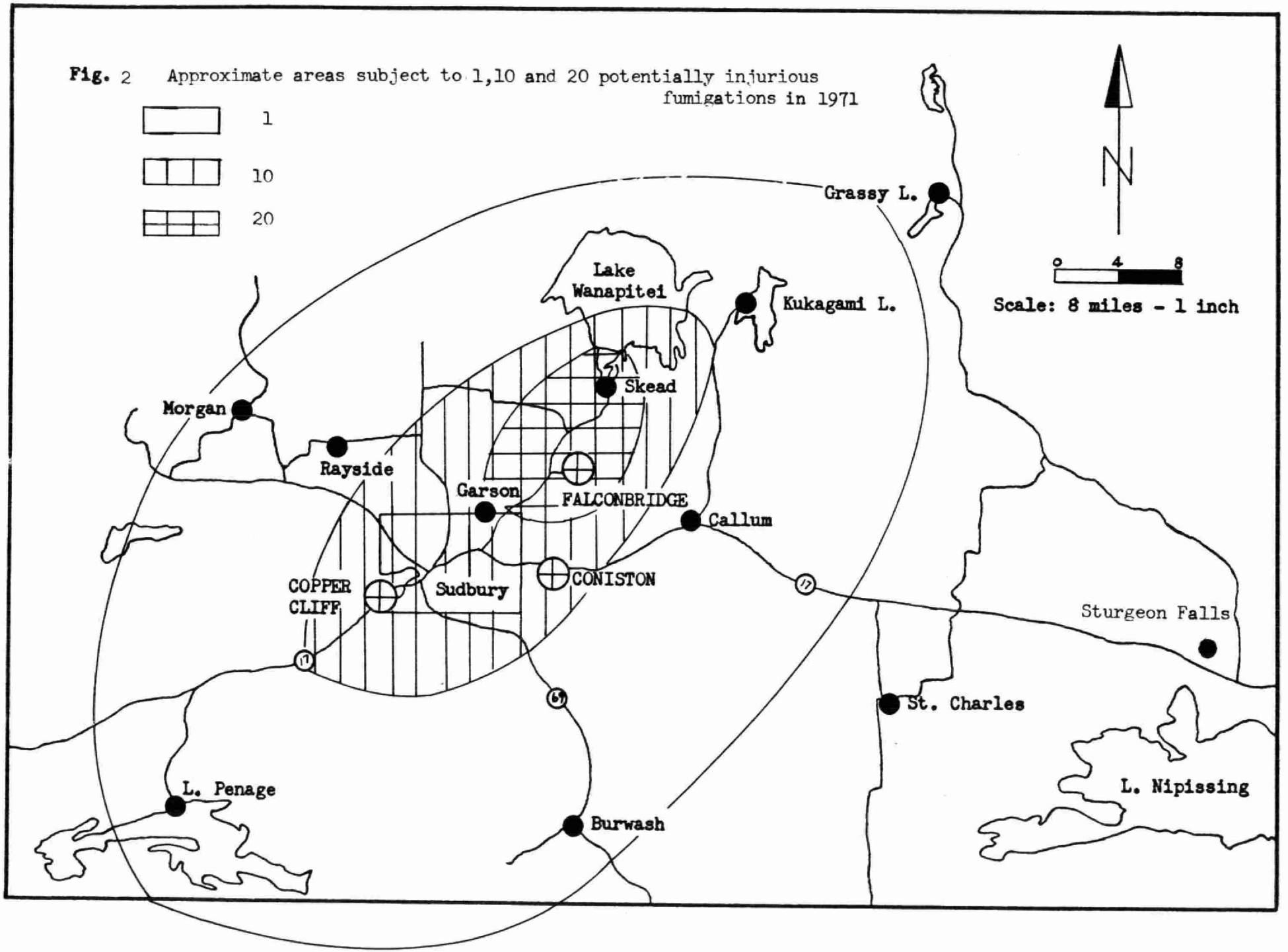
Fig. 2 Approximate areas subject to 1,10 and 20 potentially injurious fumigations in 1971
1
10
20
N
0 4 8
Scale: 8 miles - 1 inch
Grassy L.
Lake Wanapitei
Kukagami L.
Skead
Morgan
Rayside
Garson
FALCONBRIDGE
Callum
CONISTON
COPPER CLIFF
Sudbury
17
Sturgeon Falls
St. Charles
69
L. Penage
Burwash
L. Nipissing

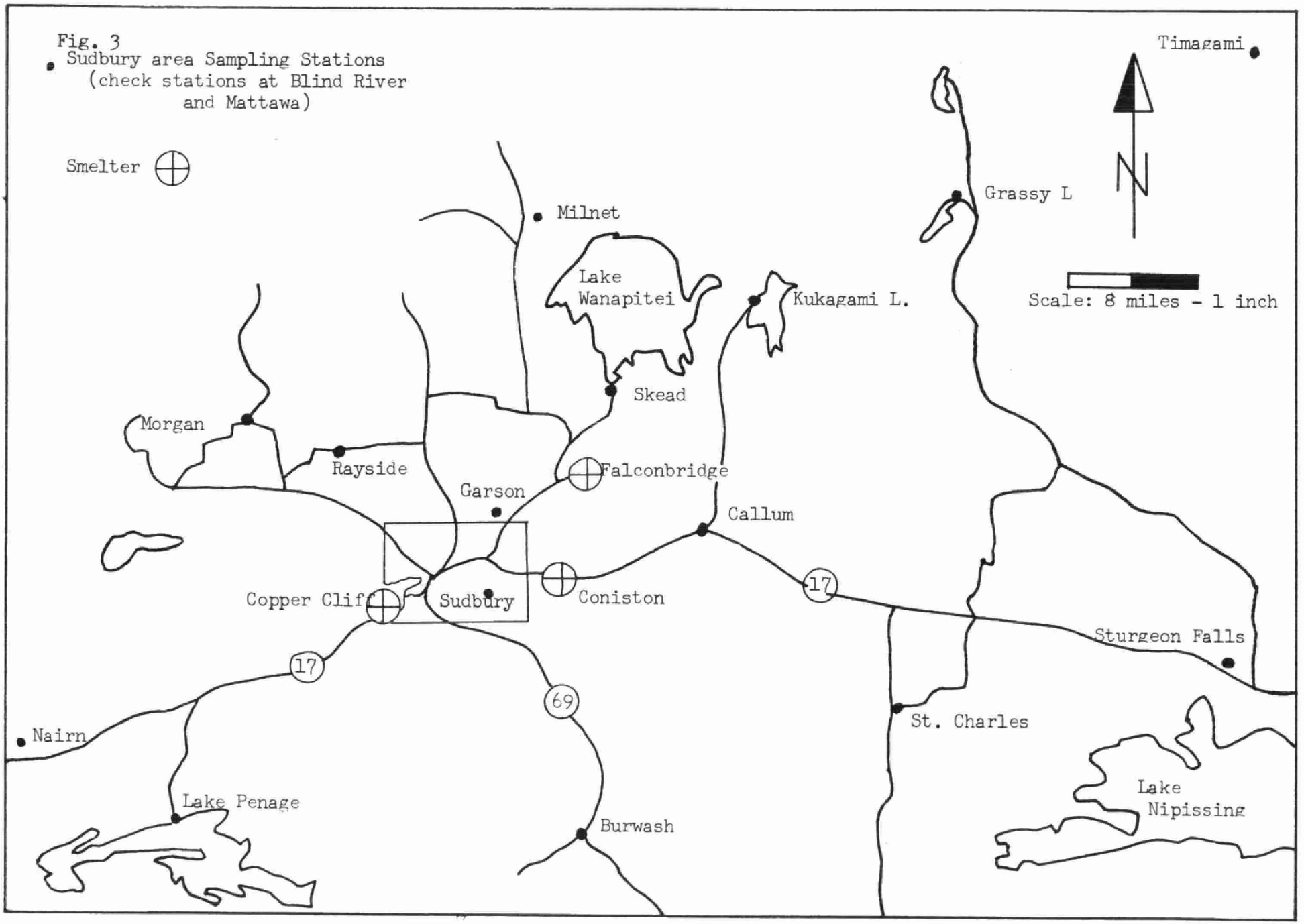
Fig. 3
Sudbury area Sampling Stations
(check stations at Blind River
and Mattawa)
Smelter
Timagami
Grassy L
N
Scale: 8 miles - 1 inch
Milnet
Lake
Wanapitei
Kukagami L.
Skead
Morgan
Rayside
Falconbridge
Garson
Callum
Copper Cliff
Sudbury
Coniston
17
Sturgeon Falls
St. Charles
69
Nairn
Lake Penage
Burwash
Lake
Nipissing

Fig. 4

Relationship between the air candle sulphation rate
and Total Sulphur (%) in Vegetation Samples
Sudbury area 1970

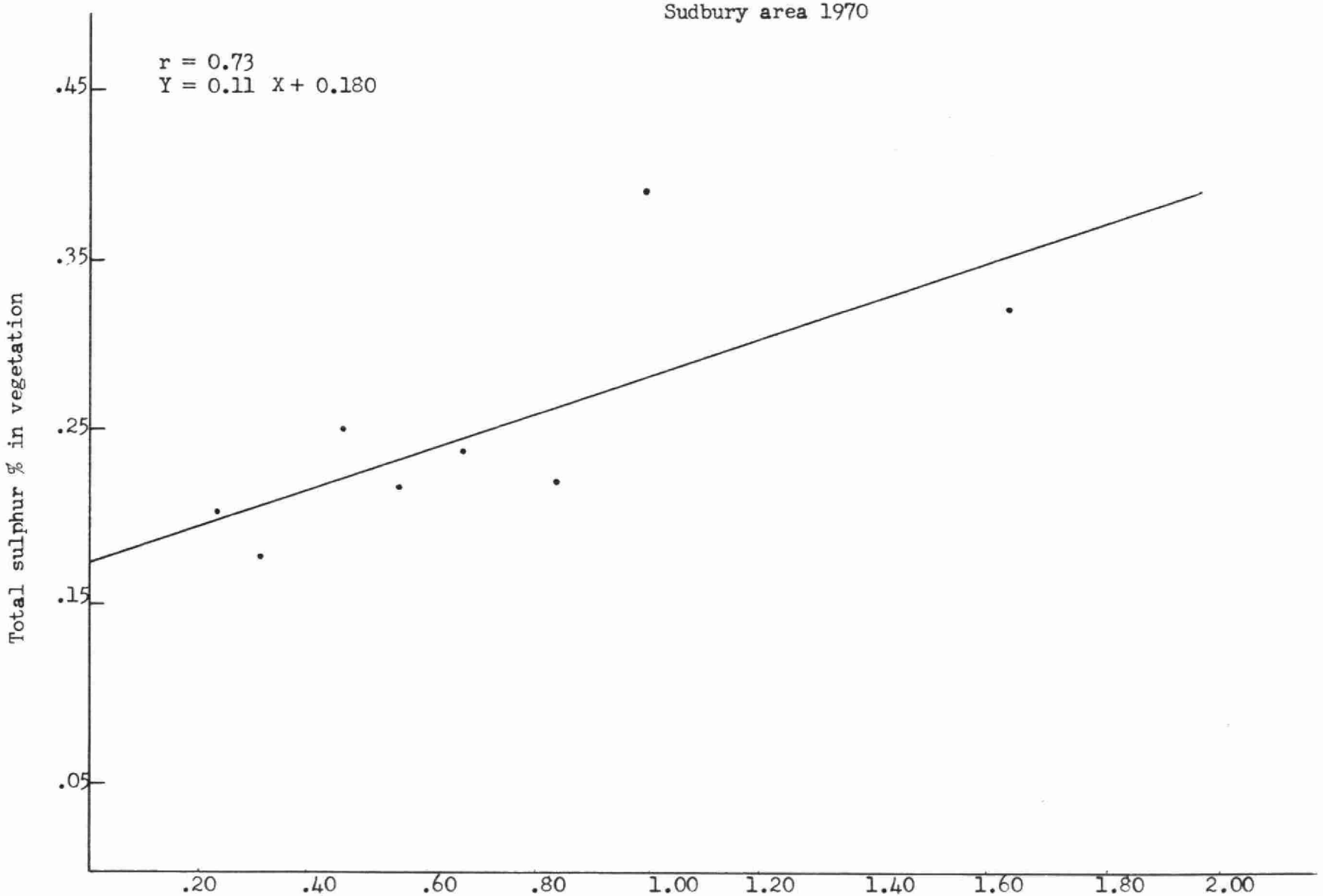

Fig. 5

Relationship between the air candle sulphation rate and SO_4-S(%) in vegetation samples
Sudbury area 1970

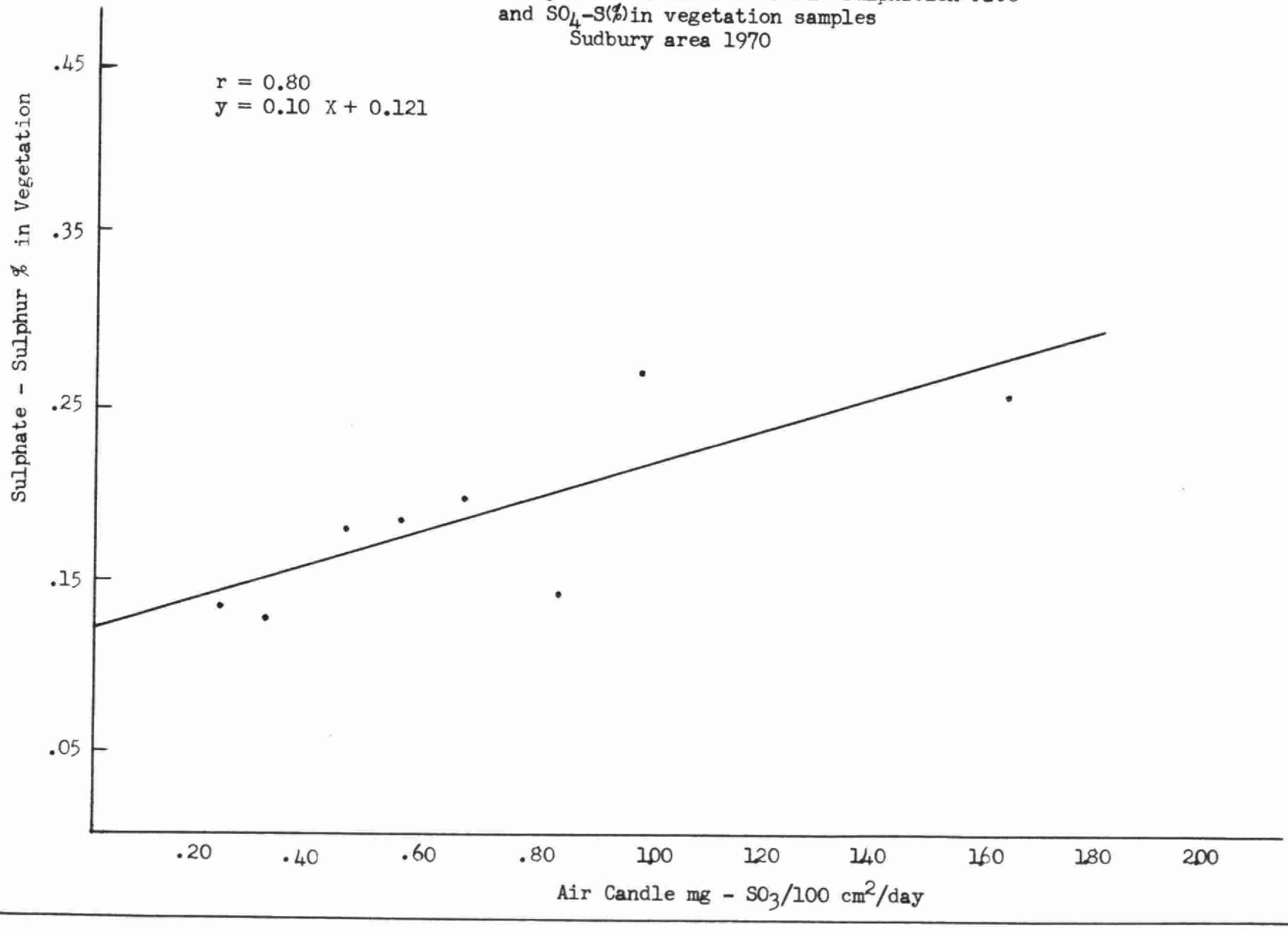

Table 1 Location of Sulphur Dioxide Recorders in relation to the three smelters in the Sudbury area

Station	Location in relation to smelter								
	Copper Cliff			Coniston			Falconbridge		
	Wind*	Degrees	Miles	Wind*	Degrees	Miles	Wind*	Degrees	Miles
Garson	SW	53	8.0	SE	309	5.6	NE	248	6.6
Skead	SW	48	19.2	S	19	12.4	S	21	5.8
Kukagami	SW	55	28.0	SW	52	19.2	SW	41	14.4
Grassy	SW	56	43.8	SW	47	35.0	SW	55	29.6
Penage	NE	225	19.2	NE	239	28.0	NE	231	33.0
Morgan	SE	310	14.0	SE	297	21.6	SE	280	21.4
Burwash	NW	140	18.4	N	174	15.2	N	180	21.4
Rayside	S	352	9.6	SE	305	28.8	E	280	13.4
St. Charles	W	103	32.8	W	112	23.0	NW	127	24.4
Callum	W	81	22.0	W	81	10.8	NW	116	9.8
Sturgeon Falls	W	94	53.3	W	98	42.2	NW	114	42.8

*Wind direction required to carry sulphur dioxide from that smelter to the various recorder locations.

Table 2 1971 summary of sulphur dioxide data at recorder stations

Station	SO_2 hrs.	SO_2 %	Half-hour concentrations above .25 ppm hrs.	.25 ppm %	.50 ppm hrs.	.50 ppm %	1.00 ppm hrs.	1.00 ppm %	Max. ppm ½-hr.	Average concentration (ppm) for SO_2 periods only Mean*	SO_2 periods only 1971	Total period Mean*	Total period 1971
						-May-							
Garson	100.5	17.1	17.0	2.9	6.5	1.1	1.0	0.2	1.44	.143	.15	.0313	.03
Skead	149.0	25.1	35.5	6.0	9.0	1.5	2.0	0.0	1.73	.199	.06	.0394	.05
Kukagami	-	-	-	-	-	-	-	-	-	.089	-	.0162	-
Grassy	-	-	-	-	-	-	-	-	-	.070	-	.0056	-
Penage	26.5	9.7	2.0	0.7	0.5	0.2	0.0	0.0	0.70	.122	.11	.0106	<.01
Morgan	57.5	15.1	0.5	0.1	0.0	0.0	0.0	0.0	0.31	.085	.02	.0079	.01
Burwash	27.5	8.0	2.0	0.5	0.0	0.0	0.0	0.0	0.39	.083	.08	.0111	.01
Rayside	23.5	5.0	2.5	0.5	2.0	0.4	0.0	0.0	0.72	.147	.12	.0186	.01
St. Charles	8.0	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.12	.046	.04	.0024	<.01
Callum	26.0	8.0	4.0	0.1	0.5	0.0	0.0	0.0	0.64	.079	.12	.0113	.01
Sturgeon Falls**	28.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.21	-	.04	-	<.01
						-June-							
Garson	248.5	41.3	57.5	9.6	20.5	3.4	1.5	0.2	1.46	.171	.17	.0398	.08
Skead	234.5	32.6	72.0	10.0	17.0	2.3	2.0	0.2	1.66	.212	.19	.0484	.06
Kukagami	72.5	43.2	0.5	0.3	0.0	0.0	0.0	0.0	0.29	.094	.03	.0181	.02
Grassy	47.5	17.1	0.0	0.0	0.0	0.0	0.0	0.0	0.17	.077	.04	.0097	.01
Penage	66.0	9.2	4.2	0.6	1.0	0.1	0.0	0.0	0.63	.144	.08	.0129	.01
Morgan	105.5	16.6	5.0	0.8	1.5	0.2	0.0	0.0	0.61	.068	.06	.0031	.01
Burwash	33.5	4.6	0.0	0.0	0.0	0.0	0.0	0.0	0.17	.088	.05	.0122	<.01
Rayside	57.0	8.7	12.5	1.9	4.5	0.7	1.0	0.2	1.06	.133	.17	.0104	.02
St. Charles	45.0	6.4	0.0	0.0	0.0	0.0	0.0	0.0	0.15	.054	.02	.0026	<.01
Callum	115.5	16.2	14.0	1.9	0.5	0.1	0.0	0.0	0.65	.101	.10	.0129	.02
Sturgeon Falls**	7.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.04	-	.01	-	<.01

*Mean is average of 1953-1970 inclusive data - does not include data during three strikes in 1958,1966 and 1969

**Data available for 1971 season only

Table 2 cont'd — 1971 summary of sulphur dioxide data at recorder stations

Station	SO_2 hrs.	SO_2 %	Half-hour concentrations above .25 ppm hrs.	.25 ppm %	.50 ppm hrs.	.50 ppm %	1.00 ppm hrs.	1.00 ppm %	Max. ppm ½-hr.	Average concentrations (ppm) for SO_2 periods only Mean*	SO_2 periods only 1971	Total period Mean*	Total period 1971
							-July-						
Garson	81.0	15.2	18.0	3.3	4.0	0.7	2.0	0.3	1.23	.158	.17	.0337	.03
Skead	310.0	42.9	35.5	5.0	5.5	0.8	0.0	0.0	0.90	.183	.08	.0397	.05
Kukagami	137.0	19.9	15.0	2.3	5.0	0.8	0.5	0.1	1.11	.087	.12	.0155	.03
Grassy	91.0	12.9	1.0	0.1	0.0	0.0	0.0	0.0	0.32	.070	.04	.0084	.01
Penage	16.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.20	.105	.04	.0040	<.01
Morgan	92.0	14.6	0.0	0.0	0.0	0.0	0.0	0.0	0.09	.103	.01	.0051	<.01
Burwash	32.0	4.4	1.0	0.1	0.0	0.0	0.0	0.0	0.28	.092	.09	.0130	<.01
Rayside	14.5	2.2	3.0	0.4	0.0	0.0	0.0	0.0	0.38	.161	.12	.0104	<.01
St. Charles	67.5	9.2	0.0	0.0	0.0	0.0	0.0	0.0	0.25	.058	.03	.0045	<.01
Callum	111.5	15.0	8.5	1.1	0.5	0.1	0.0	0.0	0.68	.089	.08	.0147	.01
Sturgeon Falls**	25.5	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.16	-	.03	-	<.01
							-Aug.-						
Garson	111.5	16.3	31.5	4.6	9.5	1.5	1.5	0.2	1.21	.158	.22	.0320	.03
Skead	465.5	62.6	20.5	2.6	5.0	0.7	0.0	0.0	0.92	.188	.05	.0356	.03
Kukagami	99.5	16.6	15.0	2.5	3.0	0.5	0.5	0.1	1.17	.092	.12	.0132	.02
Grassy	20.0	16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.11	.070	.03	.0071	.01
Penage	65.5	8.7	9.0	1.3	1.0	0.1	0.0	0.0	0.91	.109	.12	.0077	.01
Morgan	82.5	12.2	0.5	0.1	0.0	0.0	0.0	0.0	0.32	.059	.02	.0035	<.01
Burwash	99.0	13.3	2.5	0.3	0.5	0.0	0.0	0.0	0.60	.095	.06	.0117	.01
Rayside	15.0	2.4	0.5	0.1	0.0	0.0	0.0	0.0	0.40	.127	.09	.0099	<.01
St. Charles	40.5	7.4	0.0	0.0	0.0	0.0	0.0	0.0	0.20	.054	.03	.0039	<.01
Callum	127.5	17.1	5.0	7.0	1.5	0.2	0.5	0.1	1.22	.100	.08	.0173	.02
Sturgeon Falls**	20.5	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.11	-	.04	-	<.01

*Mean is average of 1953-1970 inclusive data-does not include data during three strikes in 1958,1966, and 1969

**Data available for 1971 season only

Table 2 cont'd — 1971 summary of sulphur dioxide data at recorder stations

Station	SO_2 hrs.	SO_2 %	Half-hour concentrations above .25 ppm hrs.	.25 ppm %	.50 ppm hrs.	.50 ppm %	1.00 ppm hrs.	1.00 ppm %	Max. ppm ½-hr.	Average concentration (ppm) for SO_2 periods only Mean*	SO_2 periods only 1971	Total period Mean*	Total period 1971
						-Sept.-							
Garson	61.5	8.7	14.5	2.0	5.0	0.8	0.5	0.1	1.08	.151	.19	.0254	.02
Skead	228.5	32.2	48.5	6.8	15.0	2.1	4.0	0.6	1.97	.218	.15	.0478	.05
Kukagami	98.0	14.1	20.5	2.9	5.5	0.7	1.5	0.2	1.40	.091	.17	.0125	.02
Grassy	84.0	11.8	0.5	0.6	0.0	0.0	0.0	0.0	0.29	.072	.05	.0061	.01
Penage	29.5	4.2	1.5	0.3	0.0	0.0	0.0	0.0	0.39	.107	.09	.0068	<.01
Morgan	75.0	10.8	0.6	0.9	3.0	0.4	0.0	0.0	0.71	.063	.08	.0045	.01
Burwash	61.5	8.6	0.6	0.8	1.0	0.1	0.0	0.0	0.68	.098	.10	.0116	.01
Rayside	82.5	11.9	7.5	1.1	2.5	0.4	0.5	0.1	1.01	.145	.11	.0043	.01
St. Charles	37.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.09	.051	.03	.0005	<.01
Callum	81.0	11.3	5.5	0.8	1.5	0.2	0.0	0.0	0.62	.100	.08	.0146	.01
Sturgeon Falls**	37.5	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.11	-	.02	-	<.01
						-Oct.-							
Garson	78.0	15.2	3.5	0.7	0.0	0.0	0.0	0.0	0.35	.145	.08	.0243	.01
Skead	159.5	21.4	34.5	4.6	13.0	1.7	1.5	0.2	1.37	.254	.17	.0515	.04
Kukagami	57.0	9.6	3.5	0.6	0.0	0.0	0.0	0.0	0.34	.102	.09	.0142	.01
Grassy	30.0	8.2	0.0	0.0	0.0	0.0	0.0	0.0	0.20	.078	.03	.0080	<.01
Penage	38.0	7.7	12.5	2.6	1.0	0.2	0.0	0.0	0.63	.116	.17	.0070	.01
Morgan	117.0	17.0	7.0	1.0	0.5	0.7	0.0	0.0	0.53	.066	.06	.0065	.01
Burwash	33.0	4.6	4.0	0.6	0.0	0.0	0.0	0.0	0.40	.097	.10	.0125	<.01
Rayside	97.5	15.5	23.5	3.7	6.0	1.0	1.0	0.2	1.37	.113	.15	.0128	.02
St. Charles	22.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.12	.058	.03	.0047	<.01
Callum	31.5	11.6	6.0	2.2	1.0	0.3	0.0	0.0	0.70	.094	.13	.0122	.02
Sturgeon Falls**	19.5	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.15	-	.03	-	<.01

* Mean is average of 1953-1970 inclusive data-does not include data during three strikes in 1958,1966, and 1969

** Data available fro 1971 season only

Table 3 Yearly summary of SO2 data for the Sudbury area.

Station	Low	Year	High	Year	1971
	* Percentage frequency of SO2				
Garson	11.61	1953	25.02	1962	18.80
Skead	13.40	1954	36.50	1971	36.50
Kukagami	7.78	1954	26.96	1963	16.90
Grassy	3.39	1954	15.87	1964	12.50
Penage	4.59	1953	9.40	1956	6.50
Morgan	3.56	1963	14.20	1971	14.20
Burwash	6.59	1953	21.39	1962	7.10
Rayside	4.37	1957	13.85	1968	7.70
St. Charles	3.65	1957	10.11	1960	6.40
Callum	11.85	1970	17.13	1963	14.00
**Sturgeon Falls	-	-	-	-	3.10
	* Percentage frequency of SO2 above 0.25 ppm				
Garson	1.13	1953	5.14	1960	3.90
Skead	4.21	1954	8.12	1961	5.80
Kukagami	0.29	1954	1.80	1967	2.00
Grassy	0.00	1953	0.78	1961	0.00
Penage	0.33	1962	1.27	1954	0.80
Morgan	0.16	1968	0.93	1962	0.51
Burwash	0.30	1971	1.84	1960	0.30
Rayside	0.81	1963	2.29	1970	1.30
St. Charles	0.00	1971	0.34	1961	0.00
Callum	0.53	1962	1.65	1963	1.20
**Sturgeon Falls	-	-	-	-	0.00
	Maximum half-hour concentrations (ppm)				
Garson	1.16	1953	3.06	1962	1.46
Skead	1.31	1959	3.64	1956	1.97
Kukagami	0.49	1956	1.24	1961	1.40
Grassy	0.24	1953	0.77	1966	0.32
Penage	0.44	1969	1.65	1965	0.91
Morgan	0.52	1964	1.24	1967	0.71
Burwash	0.41	1966	1.39	1954	0.68
Rayside	0.94	1964	1.71	1970	1.37
St. Charles	0.30	1962	0.95	1959	0.25
Callum	0.62	1969	1.63	1965	1.22
**Sturgeon Falls	-	-	-	-	0.21

* Does not include 1958, 1966, and 1969 (strike years)

** Data available for 1971 season only

Table 4

Sudbury Percentage Frequencies of **Wind Directions**

	May		June		July		August		September		October		Season (May-Oct.)	
Wind	Mean* %	1971 %	Mean* %	1971 %	Mean* %	1971 %	Mean* %	1971 %	Mean* %	1971 %	Mean* %	1971 %	Mean* %	1971 %
N	16.4	19.2	15.6	11.0	14.0	10.8	14.7	11.3	13.1	13.6	13.6	3.6	14.6	11.6
NE	11.9	18.1	11.7	12.5	7.8	5.4	9.2	10.1	8.4	5.0	7.5	15.6	9.5	11.1
E	5.8	7.8	4.9	7.4	4.1	2.3	5.1	7.0	5.5	3.9	8.2	9.7	5.6	6.3
SE	7.7	1.5	5.1	5.5	3.1	2.5	6.7	0.9	9.5	8.5	11.6	4.4	7.6	3.9
S	15.3	12.0	15.5	14.9	12.6	16.5	13.3	7.1	17.5	21.4	17.8	30.0	15.4	17.0
SW	19.0	19.4	22.4	31.8	22.2	29.2	19.2	22.9	16.5	21.1	14.9	19.5	19.0	24.0
W	12.5	12.6	13.8	10.3	20.6	20.3	19.2	21.8	17.3	14.4	14.9	7.7	16.4	14.5
NW	10.7	7.7	10.4	2.6	13.5	10.3	12.3	16.1	11.4	8.2	10.8	7.1	11.5	8.7
C	5.3	1.7	0.4	4.0	0.3	2.7	0.3	2.8	0.8	3.9	0.6	2.4	0.5	2.9
Prevailing wind	SW	SW	SW	SW	SW	SW	SW&W	SW	S	S	S	S	SW	SW

*Mean - 1953 to 1970 inclusive

Table 5 No. of days (between sunrise and sunset) in six-month period (May to October) 1971 when potentially injurious fumigations were recorded

Station		No. of days recorders were operating	Days with SO_2	Days at or above limits**	Max. Intensity	Max. av. conc. for 1 hr. ppm	2 hr. ppm	4 hr. ppm	8 hr. ppm
Garson	1971	178	120	18	240	1.22	0.99	0.83	0.60
	Low		66('69)	8('69)	169('54)	0.92	0.80	0.55	0.38
	High		129('68)	35('63)	343('62)	2.00	1.63	1.20	0.67
Skead	1971	178	133	24	252	1.62	1.30	0.88	0.53
	Low		67('57)	11('66)	156('66)	1.02	0.78	0.48	0.38
	High		133('71)	29('61)	473('68)	3.57	2.60	1.51	0.88
Kukagami	1971	131	67	5	220	1.28	1.17	0.77	0.43
	Low		27('54)	0('55)	89('55)	0.45	0.40	0.31	0.20
	High		93('61)	6('61)	220('71)	1.28	1.17	0.77	0.54
Grassy	1971	123	60	0	57	0.29	0.24	0.20	0.13
	Low		23('54)	0*	36('54)	0.24	0.18	0.12	0.08
	High		79('64)	2('57)	108('57)	0.70	0.50	0.37	0.27
Penage	1971	165	46	3	120	0.84	0.58	0.37	0.30
	Low		25('60)	0*	68('69)	0.37	0.25	0.21	0.16
	High		49('69)	6*	200*	1.12	0.96	0.70	0.50
Morgan	1971	171	103	1	126	0.63	0.60	0.44	0.24
	Low		20('66)	0*	66('64)	0.44	0.35	0.22	0.11
	High		103('71)	5('67)	166('67)	1.00	0.67	0.58	0.33
Burwash	1971	168	56	1	106	0.61	0.49	0.37	0.21
	Low		33('69)	0*	69*	0.39	0.36	0.24	0.15
	High		85('64)	8('54)	224('61)	1.14	0.85	0.76	0.56
Rayside	1971	175	60	8	188	1.24	0.83	0.59	0.47
	Low		23('57)	3('64)	122('64)	0.69	0.46	0.34	0.24
	High		66('62)	11('68)	272('67)	1.64	1.24	0.90	0.68
St. Charles	1971	164	46	0	26	0.18	0.12	0.09	0.05
	Low		28('69)	0*	26('71)	0.18	0.12	0.09	0.05
	High		60*	1*	140('69)	0.76	0.65	0.49	0.25
Callum	1971	152	88	1	136	0.69	0.56	0.47	0.34
	Low		51('69)	0('69)	96('69)	0.48	0.41	0.31	0.24
	High		92('64)	8('67)	335('65)	1.44	1.36	1.17	0.70
Sturgeon Falls	1971	184	49	0	25	0.18	0.14	0.07	0.04
	Low								
	High								

* record during more than 1 year

** intensity level of 100

Table 6 Concentrations of the Various Chemical Elements in the Vegetation collected at the Sudbury Surveillance Plots during the 1970 growing season (Average of four monthly collections)

White Birch

Plot	*Location	ToS %	SO4-S %	As ppm	Co ppm	Cu ppm	F ppm	Fe ppm	Ni ppm	Se ppm	Zn ppm
					Chemicals						
Blind River	100 m. W	.12	.09	0.5	2.0	8	0	54	3	-	296
Mattawa	110 m. E	.17	.09	0.6	2.0	10	2	54	3	.70	270
Sudbury	Laurn. U.	.29	.25	0.6	3.0	26	3	162	58	-	90
Garson	3 m. NE	.41	.28	2.0	2.0	61	4	235	84	1.06	114
Skead	16 m. NE	.37	.30	4.4	2.4	59	3	423	97	.79	188
Kukagami L.	26 m. NE	.27	.24	2.2	2.2	39	2	321	46	.93	213
Grassy L.	40 m. NE	.18	.16	0.5	2.2	11	0	103	13	.79	237
Timagami	50 m. NE	.22	.13	0.6	2.2	20	2	137	14	.74	151
Rayside	10 m. NW	.24	.15	0.7	2.2	24	3	130	45	-	87
Morgan	15 m. NW	.17	.11	0.5	2.2	19	3	140	18	-	205
Milnet	23 m. N	.25	.15	1.4	2.2	26	6	141	42	-	158
Callum	18 m. E	.24	.18	1.1	2.2	23	2	125	44	-	125
St. Charles	30 m. SE	.15	.15	0.7	2.2	14	3	110	16	-	239
Sturgeon Falls	48 m. E	.17	.12	0.7	2.2	13	4	44	7	-	291
Burwash	17 m. S	.26	.13	0.7	2.2	23	4	186	31	-	76
Nairn Centre	30 m. SW	.17	.11	0.6	2.2	10	2	75	8	-	223
Penage	23 m. SW	.17	.11	0.5	2.2	22	1	74	13	.77	176

Trembling Aspen

Blind River	100 m. W	.16	.10	0.5	2.0	6	3	45	3	-	283
Mattawa	110 m. E	.19	.11	0.6	2.0	11	2	62	3	.78	262
Sudbury	Laurn. U	.33	.29	0.5	0.4	17	2	125	54	-	84
Garson	3 m. NE	.44	.29	0.6	3.7	27	3	144	99	1.12	75
Skead	16 m. NE	.37	.25	3.8	3.5	38	2	437	83	1.14	176
Kukagami L.	26 m. NE	.40	.29	0.6	3.0	22	3	184	45	.84	225
Grassy L.	40 m. NE	.22	.22	0.5	2.0	10	0	69	18	.70	163
Timagami	50 m. NE	.33	.14	0.5	2.0	21	4	159	15	.62	109
Rayside	10 m. NW	.20	.19	0.9	4.6	25	6	167	95	-	127
Morgan	15 m. NW	.20	.13	0.5	2.4	17	3	188	28	-	156
Milnet	23 m. N	.26	.18	0.9	2.8	23	2	159	78	-	238
Callum	18 m. E	.27	.29	1.0	3.7	14	2	98	96	.87	131
St. Charles	30 m. SE	.20	.18	0.8	3.3	15	4	124	12	-	171
Sturgeon Falls	48 m. E	.18	.14	0.5	2.0	10	7	45	9	-	570
Burwash	17 m. S	.32	.23	0.7	2.0	21	4	173	36	-	125
Nairn Centre	30 m. SW	.21	.16	0.6	3.0	11	2	81	15	-	265
Penage	23 m. SW	.23	.18	0.5	3.1	19	2	74	28	.94	191

* Distance and Direction from Sudbury
- underlined values are markedly higher than the controls
- Blind River and Mattawa are control plots

Table 6 cont'd — Concentrations of the Various Chemical Elements in the Vegetation collected at the Sudbury Surveillance Plots during the 1970 growing season (Average of four monthly collections)

Bracken Fern

Plot	*Location	ToS %	SO4-S %	As ppm	Co ppm	Cu ppm	F ppm	Fe ppm	Ni ppm	Se ppm	Zn ppm
					Chemicals						
Blind River	100 m. W	.10	.07	0.5	2	3	0	61	1	-	29
Mattawa	110 m. E	.14	.08	0.5	2	9	6	77	2	.33	51
Sudbury	Laurn. U.	.21	.18	0.5	2	21	1	115	66	-	54
Garson	3 m. NE	.22	.25	0.9	2	24	3	160	67	.73	29
Skead	16 m. NE	.26	.19	2.3	2	17	3	211	36	.48	34
Kukagami L.	26 m. NE	.19	.13	0.7	2	10	1	108	24	.46	33
Grassy L.	40 m. NE	.14	.14	0.8	2	6	2	99	3.3	.37	29
Timagami	50 m. NE	.15	.09	0.5	2	13	2	162	6	.50	34
Rayside	10 m. NW	.21	.12	0.5	3	16	0	136	51	-	26
Morgan	15 m. NW	.20	.17	0.5	2	8	1	103	7	-	19
Milnet	23 m. N	.16	.12	0.6	2	13	1	111	20	-	30
Callum	18 m. E	.18	.13	1.0	2	20	1	182	42	-	21
St. Charles	30 m. SE	.13	.10	0.5	2	8	1	152	6	-	29
Sturgeon Falls	48 m. E	.12	.09	0.6	2	4	3	65	2	-	35
Burwash	17 m. S	.19	.18	0.8	2	20	2	164	23	-	28
Nairn Centre	30 m. SW	.13	.10	0.6	2	2	2	102	9	-	33
Penage	23 m. SW	.14	.10	1.3	2	9	4	106	9	.46	38

Forage

Blind River	100 m. W	.14	.11	0.5	2	9	0	40	2	-	29
Mattawa	110 m. E	.20	.13	0.5	2	9	3	100	3	.52	36
Sudbury	Laurn. U.	.22	.17	0.5	2	18	2	121	24	-	20
Garson	3 m. NE	.40	.27	2.1	2	35	5	122	15	.81	20
Skead	16 m. NE	.41	.29	1.2	2	36	3	234	33	.67	42
Kukagami L.	26 m. NE	.31	.26	0.9	2	18	1	112	22	.58	40
Grassy L.	40 m. NE	.28	.25	0.5	2	12	2	73	6	.48	35
Timagami	50 m. NE	.19	.12	0.5	2	12	2	148	3	.45	27
Rayside	10 m. NW	.27	.18	0.5	2	14	2	139	30	-	22
Morgan	15 m. NW	.29	.21	0.5	2	13	2	115	19	-	29
Milnet	23 m. N	.30	.23	0.5	2	15	2	98	37	-	36
Callum	18 m. E	.25	.19	0.7	2	16	1	110	30	-	29
St. Charles	30 m. SE	.22	.17	0.5	2	10	2	97	7	-	27
Sturgeon Falls	48 m. E	.14	.11	0.5	2	11	2	82	3	-	25
Burwash	17 m. S	.25	.15	1.2	2	17	2	108	20	-	22
Nairn Centre	30 m. SW	.19	.15	0.5	2	8	0	59	5	-	19
Penage	23 m. SW	.23	.18	0.5	2	19	.5	79	7	.57	39

* Distance and Direction from Sudbury
- underlined values are markedly higher than the controls
- Blind River and Mattawa are control plots
- For Cobalt, a value of 2 ppm means less than 2 ppm

Table 6 cont'd

Concentrations of the Various Chemical Elements in the Vegetation collected at the Sudbury Surveillance Plots during the 1970 growing Season (Average of four monthly collections)

Jack Pine

Plot	*Location	Chemicals ToS %	SO4-S %	As ppm	Co ppm	Cu ppm	F ppm	Fe ppm	Ni ppm	Se ppm	Zn ppm
Blind River	100 m. W	.10	.03	0.5	2.0	2	1	24	2	-	66
Mattawa	110 m. E	.12	.03	0.5	2.0	5	3	36	3	.43	74
Sudbury	Laurn. U.	.14	.07	0.5	2.0	9	2	47	26	-	53
Garson	3 m. NE	-	-	-	2.0	-	-	-	-	-	-
Skead	16 m. NE	.22	.13	1.7	2.0	28	1	306	60	.46	29
Kukagami L.	26 m. NE	.19	.06	0.6	2.0	15	3	118	39	.45	29
Grassy L.	40 m. NE	.11	.07	0.5	2.0	6	0	60	16	.57	44
Timagami	50 m. NE	.14	.06	0.6	2.0	12	0	97	18	.49	74
Rayside	10 m. NW	.14	.06	0.5	2.0	13	0	113	40	-	23
Morgan	15 m. NW	.15	.06	0.6	2.0	8	1	91	15	-	40
Milnet	23 m. N	.14	.07	0.5	2.0	18	2	84	25	-	55
Callum	18 m. E	.16	.07	0.7	2.0	9	3	52	32	-	20
St. Charles	30 m. SE	.10	.06	0.5	2.0	5	1	64	9	-	47
Sturgeon Falls	48 m. E	-	-	-	2.0	-	-	-	-	-	-
Burwash	17 m. S	.12	.07	0.5	2.0	6	1	70	22	-	30
Nairn Centre	30 m. SW	.12	.06	0.5	2.0	3	1	40	14	-	46
Penage	23 m. SW	.13	.07	0.5	2.0	8	1	294	39	.35	30

* Distance and Direction from Sudbury
- underlined values are markedly higher than the controls
- Blind River and Mattawa are control plots
- For Cobalt, a value of 2 ppm means less than 2 ppm.

Table 6 cont'd

Concentrations of the Various Chemical Elements in the Soil collected at the Sudbury Surveillance Plots during the 1970 growing season (Average of two monthly collections)

Soil

Plot	** Location	ToS %	SO4-S meq.	Chemicals As ppm	Co ppm	Cu ppm	F ppm	Fe %	Ni ppm	Se ppm	Zn ppm
Blind River	100 m. W	.02	.13	1.7	6	10	140	*.15	11	-	37
Mattawa	110 m. E	.01	*08	2.3	2	7	185	.39	7	.08	28
Sudbury	Laurn. U.	.02	.26	10.2	9	265	50	*1.58	245	-	30
Garson	3 m. NE	.03	.25	9.8	8	174	55	*1.02	215	1.52	23
Skead	16 m. NE	.04	.34	13.1	9	125	80	*1.12	150	.29	85
Kukagami	26 m. NE	.05	.45	11.7	*7	102	90	1.60	85	.47	43
Grassy	40 m. NE	.04	.24	7.0	20	57	185	.60	68	.32	114
Timagami	50 m. NE	.04	.35	4.0	10	51	110	.98	40	.30	53
Rayside	10 m. NW	.03	.23	7.0	3	67	95	*.97	85	-	22
Morgan	15 m. NW	.01	.13	3.4	8	29	50	1.16	43	-	28
Milnet	23 m. N	.04	.16	7.2	6	33	75	.97	50	-	40
Callum	18 m. E	.04	.46	11.0	9	94	80	1.13	*60	-	49
St. Charles	30 m. SE	.04	.18	7.3	6	21	115	-	31	-	45
Sturgeon Falls	48 m. E	.03	.27	5.6	7	23	165	.17	39	-	72
Burwash	17 m. S	.02	.18	3.4	8	27	75	1.15	44	-	32
Nairn Centre	30 m. SW	.05	.39	3.9	7	44	170	.24	52	-	81
Penage	23 m. SW	.03	.28	7.2	9	58	135	.14	79	.40	173

** Distance and Direction from Sudbury
* Based on one monthly collection
- underlined values are markedly higher than the controls
- Blind River and Mattawa are control plots

Table 7 Summary of Analysis of Variance (F - values) for different Chemicals in the Sudbury Area in 1970

Chemicals	ToS	SO4-S	As	Co	Cu	F	Fe	Ni	Se	Zn
Sources of Variance										
Species	18.44**	11.95**	2.33	1.42	8.81**	2.13	2.88*	14.28**	30.24**	46.82**
Stations	14.62**	7.65**	10.74**	1.09	12.03**	0.86	8.62**	10.16**	8.18**	3.08**

** Significant at the 1% level

* Significant at the 5% level

Table 8

The Correlation Coefficient and Regression Equation of the Air Candle Sulphation Rate and Total Sulphur and Sulphate-Sulphur Concentration in Vegetation Sampling

Sudbury 1970

Vegetation Sampling Station	**Location	Average Sulphation rate mgm $SO_3/100cm^2/day$	Mean and Standard Error of Total Sulphur (%)	Mean and Standard Error of Sulphate-Sulphur (%)
Penage	23 miles SW	0.306	0.184 ± 0.010	0.130 ± 0.010
Sudbury	Laurn. U.	0.658	0.243 ± 0.023	0.200 ± 0.026
Burwash	17 miles S	0.450	0.258 ± 0.026	0.182 ± 0.028
Callum	18 miles E	0.547	0.226 ± 0.017	0.186 ± 0.024
Skead	16 miles NE	1.632	0.331 ± 0.027	0.269 ± 0.039
Rayside	10 miles NW	0.834	0.228 ± 0.015	0.145 ± 0.014
Garson	3 miles NE	0.984	0.397 ± 0.031	0.276 ± 0.024
Morgan	15 miles NW	0.220	0.210 ± 0.014	0.137 ± 0.014

<u>Total Sulphur</u>

Correlation Coefficient $r = 0.73^*$
Regression Equation $Y = 0.17\ X + 0.114$

<u>Sulphate-sulphur</u>

Correlation Coefficient $r = 0.80^*$
Regression Equation $Y = 0.10\ X + 0.121$

* Significant at 5% level

** Distance and Direction from Sudbury

MOE/SUD/SUL/ANXD
McGovern, P C
Sulphur dioxide
levels and environmental studies in anxd
the Sudbury area during 1971.
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